TRAFFIC TOLERANCE AND RECOVERY OF BERMUDAGRASS

A Thesis

by

WILLIAM DUSTAN ROBINSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2005

Major Subject: Agronomy

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Approved as to style and content by:

Richard White (Chair of Committee)	Frank M. Hons (Member)
Joseph P. Krausz (Member)	Mark A. Hussey (Head of Department)

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ABSTRACT

Traffic Tolerance and Recovery of Bermudagrass. (May 2005)

William Dustan Robinson, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Richard White

Bermudagrass is the predominant turfgrass used for athletic fields in the southern United States. Numerous bermudagrass cultivars are utilized for sports field use. Two frequent variations in management among facilities include mowing and nitrogen fertility regimes. Research is needed to determine the influence of bermudagrass cultivar, mowing regime, and nitrogen fertility on traffic tolerance. Research conducted at Texas A&M Univeristy studied the traffic tolerance of Tifsport, GN-1, Princess, and NuMex Sahara bermudagrasses. These grasses were mowed once weekly at 3.80 cm and three times weekly at 1.90 cm and fertilized with 146, 292, 585, or 1171 kg ha^{-1} yr^{-1}. Digital images were taken before and after simulated traffic to provide a quantitative value for percent coverage. Images were analyzed for percent green canopy coverage using Sigma Scan Pro. The number of green pixels was divided by the total image pixels a yielding a percent coverage value. Shoot density, visual quality, tissue water content, and tissue dry mass values were taken monthly. Percent tissue nitrogen was taken for three months. Analysis of digital images revealed variability in traffic injury tolerance between varieties. Tifsport, GN-1, and Princess maintained higher percent coverage than NuMex Sahara. GN-1, Princess, and Tifsport were able to tolerate traffic but did not maintain acceptable quality. Lower and more frequent mowing increased shoot density and visual quality for all grasses. Increased nitrogen fertility levels

increased tissue succulence and tissue dry mass but did not affect the traffic tolerance of any variety. Increasing nitrogen fertility above 585 kg ha^{-1} yr^{-1} showed no benefit other than increasing visual color. This research provides a guide for managers to make informed decisions on cultivar selection and management practices under traffic conditions.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

Page

LIST OF TABLES

TABLE Page

LIST OF FIGURES

INTRODUCTION

Bermudagrass is the predominant turfgrass used for athletic fields in the southern United States. Numerous bermudagrass cultivars are utilized for sports field use. Two frequent variations in management among facilities include mowing and nitrogen fertility regimes. Research is needed to determine the influence of mowing regime, bermudagrass cultivar, and nitrogen fertility on traffic tolerance.

A review of the literature reveals that mowing influences the morphology and physiology of turfgrasses. Mowing at the lower end of the tolerance range increased shoot density (Turgeon, 1999);(Kim and Beard, 1985), decreased root and rhizome growth (Beard, 1973), and decreased carbohydrate storage (Dodd and Hopkins, 1958). Literature reveals that increasing the height of cut improves the traffic tolerance of cool season grasses (Youngner, 1962);(Shearman, 1989). Kim and Beard (1985) indicated that shoot density of Tifway bermudagrass decreased from a 1.27 cm to a 5.08 cm mowing height. Trenholm et al. (2000) suggested that wear tolerance is increased as shoot density is increased. Youngner(1961) found that differences in traffic tolerance existed among bermudagrass cultivars. These results support the need for research to determine if lower mowing height of bermudagrass will reduce wear tolerance as it did for cool season grasses.

This thesis follows the style and format of Crop Science.

Mowing height is influenced by turfgrass variety and use. Mowing heights of seeded cultivars are typically recommended to be higher than those for vegetatively propagated cultivars (Duble, 1996). Golf greens require a lower mowing height to provide consistent ball roll while sports fields have higher height of cut to withstand the traffic stress. Many sports turf areas maintain their turf at the lower end of the tolerance range to maintain a fast playing surface for athletes. Soccer and baseball are two sports where mowing height influences ball roll and how players react to the ball during the game.

Sports turf mowing is also influenced by the budget of the facility. Mowing height on a sports turf area is related to the frequency of cut and type of mower used. A lower budget facility mowing once per week with a rotary mower would not be able to maintain the same 1.9 cm mowing height that can be maintained by mowing seven days a week with a reel type mower. Reel mowers have been shown to improve shoot density over rotary mowers (Johnson et al., 1987), but the frequent use of rotary mowers on sports turf areas support a need to research wear tolerance of bermudagrass for budget considerations.

Nitrogen fertility influences turfgrass traffic tolerance and recovery. Nitrogen is a constituent of the chlorophyll molecule, amino acids, proteins and nucleic acids (Carrow et al., 2001). Nitrogen fertility influences shoot growth, root growth, shoot density, temperature tolerance, and recovery potential (Beard, 1973). *Agrostis palustris* Huds. was shown to recover from traffic more rapidly with increased nitrogen (Kohlmeier and Eggens, 1983). Beyond a limit, increasing rates of nitrogen fertilization favor shoot growth while depleting carbohydrate reserves and reducing root growth (Carrow et al., 2001). Excessive nitrogen fertilization decreases the traffic tolerance of cool season grasses by increasing tissue succulence (Shearman, 1989);(Beard, 1973). Bermudagrass shoot density increases with increasing rates of nitrogen fertilization (Carrow et al., 1987). Kim and Beard (1985) showed increased shoot density and number of leaves per shoot of bermudagrass as monthly nitrogen rates increased from 0.23 kg to 1.36 kg per 92.90 m^2 $month^{-1}$. Trenholm et al. (2000) suggested that increasing shoot density improved traffic tolerance of hybrid bermudagrass. Further research is needed to determine the effects of increasing nitrogen fertility on bermudagrass subjected to traffic.

Sports turf nitrogen fertility is influenced by the budget and use of the facility. A parks and recreation area may only receive minimal nitrogen input while a high profile facility may apply four times that amount to maintain a high quality athletic turf. This is a problem for managers of park and recreational sports turf, because they may have four times the traffic of the high profile facility. The result is a recreational sports turf that has little turfgrass cover, thereby increasing the potential for injury and a lower quality of play. The problems that may occur on a high fertility facility may include excess thatch accumulation that will reduce traffic tolerance and pollution from nitrogen leaching and runoff. An experiment designed to test the influence of increased nitrogen fertility on traffic tolerance would provide sports turf managers a guide to manage nitrogen fertility for field safety and environmental stewardship.

Traffic is defined as injury to a turfgrass stand from pressure, tearing, and scuffing directly on the tissues (Carrow and Petrovic, 1992). Previous traffic tolerance and recovery tests have used machines to inflict damage on turfgrass to simulate human traffic (Shearman et al., 1974);(Youngner, 1961);(Trenholm et al., 2000);(Kohlmeir and Eggens, 1983);(Evans, 1988). These traffic machines are used to simulate traffic a number of passes or to a predetermined endpoint.

This study evaluated the traffic tolerance of four bermudagrass cultivars under two different mowing regimes and four nitrogen fertility levels. The focus of this research was to provide a realistic traffic simulation to provide data for best management practices for bermudagrass athletic fields to maintain turfgrass coverage, and will allow turfgrass professionals to make informed decisions on cultivar selection and management techniques.

Objectives

1. Determine the interactive effects of mowing regime and nitrogen fertilization on the traffic tolerance and recovery of seeded and vegetative bermudagrass cultivars.
2. Determine the potential use of digital image analysis to quantify turfgrass traffic tolerance and recovery.

MATERIALS AND METHODS

Two seeded bermudagrasses were chosen for this study based on their growth characteristics. Nu-Mex Sahara (*Cynodon dactylon* [L.] Pers.) was chosen as a coarse – textured seeded bermudagrass cultivar, while Princess (*Cynodon dactylon* [L.] Pers.) was chosen as a fine – textured seeded cultivar. Tifsport[*Cynodon dactylon* [L.] Pers. X *C. transvaalensis* [Burt Davy] is a fine-textured, vegetatively propagated hybrid bermudagrass chosen because it is widely grown in the southern United States. GN-1[*Cynodon dactylon* [L.] Pers. X *C. transvaalensis* Burt Davy] is a medium-textured, vegetatively propagated hybrid bermudagrass with aggressive stolon growth and is also widely grown in the South. The recommended mowing height for seeded bermudagrass is between 2.5 cm and 5.0 cm, while the height for hybrids is between 1.25 cm and 2.5 cm.

Research was conducted at Texas A&M University on a modified sand rootzone. The Tifsport and GN-1 bermudagrass cultivars were solid sodded with washed sod to prevent soil layering on 15 August 2000. The Princess and NuMex Sahara cultivars were seeded at 73 kg ha^{-1} unhulled pure live seed on 2 October 2000. Poor establishment and winter survival required re-seeding Princess and NuMex Sahara in March 2001 at 73 kg ha^{-1} unhulled pure live seed. Bimonthly applications of fertilizer at 24.7 kg ha^{-1} (15-5-10) were applied to all grasses for establishment from June 2001 to September 2001. Plugs were taken from inner plot areas of seeded cultivars and placed on the edges to ensure uniform coverage. Glyphosate was used to prevent encroachment in narrow strips while seeded cultivars established. A coarse sand topdressing was applied at 0.25 cm in June, July, August, and September 2001 to ensure a uniform surface. All grasses were uniform and established with mowing regimes in place by 15 August 2001. Mowing regimes and nitrogen fertility regime similar to 2003 schedule were in place for 2002. This period of time was used to develop methods for traffic simulation and digital image analysis.

A split-split block experimental design with three replications was used. Main plot treatments consisted of mowing regime. Sub-plots were bermudagrass cultivars, and sub-sub plots were nitrogen fertility regimes. Mowing treatments included of two mowing regimes. Mowing regime one included mowing three days per week at 1.9 cm with a reel type mower. This regime simulated the level of management of a facility that budgets the equipment and labor to maintain reel type mowing equipment. Mowing regime two included mowing one day per week at 3.8 cm with a rotary mower. This mowing regime simulated the management of a facility that does not have the budget to maintain reel type mowing equipment or pay for increased mowing frequency. Nitrogen fertility treatments were initiated in March after the annual average date of the last frost had passed. The treatments consisted of applying ammonium sulfate to the subplots of each block with a drop type spreader. The applied nitrogen amounts simulated a range of treatments used in sports field applications and were yearly totals of 146, 252,585, and 1171 kg N ha^{-1}(Table 1). The 146 kg N ha^{-1} treatment simulated a low budget facility with low fertilizer inputs and was applied at 48.81 kg N ha^{-1} in March, July, and September. The 252 kg N ha^{-1} treatment was applied at a rate of 36.58 kg N ha^{-1} monthly from March through November. The 585 kg N ha^{-1} treatment was applied at a

Table 1. Fertilization schedule for 2003.

Nitrogen			kg ha^{-1} applied		
kg ha^{-1}	Date	Fertilizer	N	P_2O_5	K_2O
146	15-Mar	21-0-0	48.81		
	15-Mar	0-46-0		24.7	
	15-Mar	0-0-60			48.41
	1-May	0-0-60			48.41
	1-May	0-46-0		24.7	
	1-Jun	21-0-0	48.81		
	1-Jul	0-0-60			48.41
	1-Jul	0-46-0		24.7	
	1-Sep	21-0-0	48.81		
	1-Sep	0-0-60			48.41
	1-Sep	0-46-0		24.7	
Total Fertilizer			146.43	98.8	193.64
292	15-Mar	21-0-0	36.58		
	15-Mar	0-46-0		24.7	
	15-Mar	0-0-60			48.41
	1-Apr	21-0-0	36.58		
	1-May	0-0-60			48.41
	1-May	0-46-0		24.7	
	1-Jun	21-0-0	36.58		
	1-Jul	21-0-0	36.58		
	1-Jul	0-0-60			48.41
	1-Jul	0-46-0		24.7	
	1-Aug	21-0-0	36.58		
	1-Sep	21-0-0	36.58		
	1-Sep	0-0-60			48.41
	1-Sep	0-46-0		24.7	
	1-Oct	21-0-0	36.58		
	1-Nov	21-0-0	36.58		
Total Fertilizer			292.64	98.8	193.64

Table 1. Continued.

Nitrogen kg ha^{-1}	Date	Fertilizer	kg ha^{-1} applied N	P_2O_5	K_2O
585	15-Mar	21-0-0	36.58		
	15-Mar	0-46-0		24.7	
	15-Mar	0-0-60			48.41
	1-Apr	21-0-0	36.58		
	15-Apr	21-0-0	36.58		
	1-May	0-0-60			48.41
	1-May	0-46-0		24.7	
	15-May	21-0-0	36.58		
	1-Jun	21-0-0	36.58		
	15-Jun	21-0-0	36.58		
	1-Jul	21-0-0	36.58		
	1-Jul	0-0-60			48.41
	1-Jul	0-46-0		24.7	
	15-Jul	21-0-0	36.58		
	1-Aug	21-0-0	36.58		
	15-Aug	21-0-0	36.58		
	1-Sep	21-0-0	36.58		
	1-Sep	0-0-60			48.41
	1-Sep	0-46-0		24.7	
	15-Sep	21-0-0	36.58		
	1-Oct	21-0-0	36.58		
	15-Oct	21-0-0	36.58		
	1-Nov	21-0-0	36.58		
	15-Nov	21-0-0	36.58		
Total Fertilizer			585.28	98.8	193.64

Table 1. Continued.

Nitrogen			kg ha^{-1} applied		
kg ha^{-1}	Date	Fertilizer	N	P_2O_5	K_2O
1171	15-Mar	21-0-0	73.16		
	15-Mar	0-46-0		24.7	
	15-Mar	0-0-60			48.41
	1-Apr	21-0-0	73.16		
	15-Apr	21-0-0	73.16		
	1-May	0-0-60			48.41
	1-May	0-46-0		24.7	
	15-May	21-0-0	73.16		
	1-Jun	21-0-0	73.16		
	15-Jun	21-0-0	73.16		
	1-Jul	21-0-0	73.16		
	1-Jul	0-0-60			48.41
	1-Jul	0-46-0		24.7	
	15-Jul	21-0-0	73.16		
	1-Aug	21-0-0	73.16		
	15-Aug	21-0-0	73.16		
	1-Sep	21-0-0	73.16		
	1-Sep	0-0-60			48.41
	1-Sep	0-46-0		24.7	
	15-Sep	21-0-0	73.16		
	1-Oct	21-0-0	73.16		
	15-Oct	21-0-0	73.16		
	1-Nov	21-0-0	73.16		
	15-Nov	21-0-0	73.16		
Total Fertilizer			1170.56	98.8	193.64

rate of 36.58 kg N ha^{-1} bimonthly from March through November. The 1171 kg N ha^{-1} treatment was applied at a rate of 73.16 kg N ha^{-1} bimonthly from March through November. All treatments were irrigated as needed to prevent visual signs of wilting. Phosphorus and potassium were applied throughout the growing season. Phosphorus was uniformly applied to all treatments in March, May, July, and September at 24.7 kg ha^{-1} as 0-46-0. Potassium was uniformly applied in March, May, July, and September at 48.41 kg ha^{-1} as 0-0-60.

Traffic was simulated using a modified greens aerifier fitted with cleated shoes (Figure 1). Each of the four aerifier arms was fitted with a cleated soccer shoe attatched to a contoured passenger car tire. Allowing the shoe to flex as it impacted the turf to provide a more realistic simulation of foot impact. To simulate the downward weight of an 81 kg soccer player, one aerifier arm fitted with a cleated shoe was lowered onto a digital scale until 81 kg registered. Bolts were placed in position to ensure operating height at the point 81 kg registered. Two different styles of cleats were used for the simulation. Two of the aerifier arms had a molded cleat soccer shoe while the other two arms had a shoe with detatchable 2.54 cm length cleats. The cleats were randomized after each traffic simulation to prevent the same cleat type from passing over the same area. The machine was calibrated to simulate the traffic of ten soccer games. This calibration was accomplished by calculating the number of steps per square meter over seventy-five percent of a regulation World Cup soccer field. The regulation field size is 105 m by 68 m and seventy five percent of this total area is 5,355 m^2. The field size is reduced to provide a more realistic wear simulation by concentrating wear on the center of the field.

Figure 1. Modified aerifier with cleated soccer shoes.

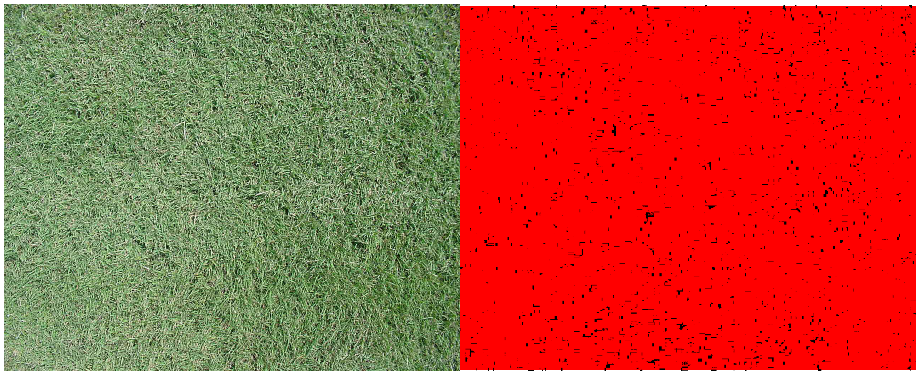
Withers et al. (1982) reported that the average soccer player travels 11, 527 m in a soccer game. Assuming a stride length of 0.5 m, each player would take 23,054 strides per game. This number of strides over the 5,355 m^2 surface area yields 4.30 steps per m^2 for one player in one game. World Cup regulations state that each team consists of 10 players and a goal keeper. This provides a total number of players on the field to be 20. The goalkeeper will be omitted because of limited movement on the field. The twenty players impact the surface an estimated 86 times per m^2 per game. The aerifier speed was set to impact the surface 16 times in 1.0 m^2. The aerifier was operated across a 1 m^2 area 5 times to simulate the 86 impacts per m^2 per game. This method contained assumptions but was an improvement over previous traffic studies where rollers were used to traffic plots a determined number of passes or to traffic the turfgrass to a predetermined endpoint. Traffic was applied to simulate a weekend soccer tournament of ten games. The turf was allowed to recover before the next traffic simulation. The recovery period between treatments differed. Rainfall or overcast conditions delayed traffic simulations. In August, the traffic simulator was broken and parts required delayed traffic simulation. In September, problems with reel – type mowing equipment delayed simulation of traffic.

Prior to the initial traffic simulation, digital images were taken of each plot for analysis of percent green canopy coverage. The method of digital analysis used was similar to the turfgrass cover method described by Richardson et al. (2001). Images were analyzed for green pixels and the number of green pixels was divided by the total number of pixels to yield a quantitative value for turfgrass coverage. Digital images were taken between 1000 to 1200 hr to ensure consistent lighting. In the future, researchers may consider using a lighted, covered box to maintain a high level of consistency as image light levels may change over the course of a study. The digital image may determine that mower scalp damage or healthy leaves determined to be damaged by light conditions altering the perception of green pixels in the image. A polyvinyl chloride (pvc) pipe frame was constructed and placed within sub-sub plots to ensure the pictures were taken from the same location in each plot. The frame was one meter high with a 0.5 meter extension arm that was positioned over the treatment. The camera was placed on the end of the extension arm to take the digital images. The pvc device and extension arm ensured that the pictures were taken of the central treatment and traffic area and there was no shadow to interfere with the digital images. The green area to be measured was based on work by Richardson et al. (2001) who used a hue value of 57 to 107 to determine the green area of Zoysiagrass. Sigma Scan Pro (v. 5.0, SPSS, Inc., Chicago, Ill) was used for analyzing images. Calibration of the image analysis program with visual observations of 100% coverage indicated that the bermudagrasses in this study demonstrated 100% coverage with a hue value of 50 to 107. Once this value was established, it was set as the default threshold value to determine green pixels in each image for all dates (Figure 2). The digital image analysis process was time consuming with each image analyzed and the number of green pixels returned to one column of a spreadsheet over multiple rows. The number of rows filled with numbers varied between each image preventing one formula from being used across all columns. Images of the 96 treatment plots were taken before and after each of the seven traffic events. This is over 1300 digital images to be analyzed. A program is needed to provide a less time consuming method to analyze large numbers of images. Traffic was applied on 2 and 17 June, 2 and 22 July, 5 August, 3 and 30 September.

Shoot densities were measured monthly from a portion of the plot not subjected to wear. Shoot density measurements were made by taking a 5.1 cm deep by 5.1 cm diameter cores from each sub-sub plot using a randomly selected grid location preselected for each month. Shoot densities were measured on 23 June, 27 July, 30 August, 30 September, and 30 October. After removal, the plugs were carefully brushed to remove any shoot tissue that did not originate within the sampled area. Only shoots originating within the sample and that had at least three leaves originating from a node were counted. GN-1 and Princess bermudagrass have a prostrate growth habit and there may be many leaves per shoot but few shoots as defined above. The purpose of this exercise was to measure the possible recovery potential of each grass in relation to the growing points at the soil surface.

Clipping weights were collected one day each month from June to October. Measurements were taken the final week of each month before the monthly fertilizer applications. Clippings from 3.8 cm mowing regime clippings were collected using a

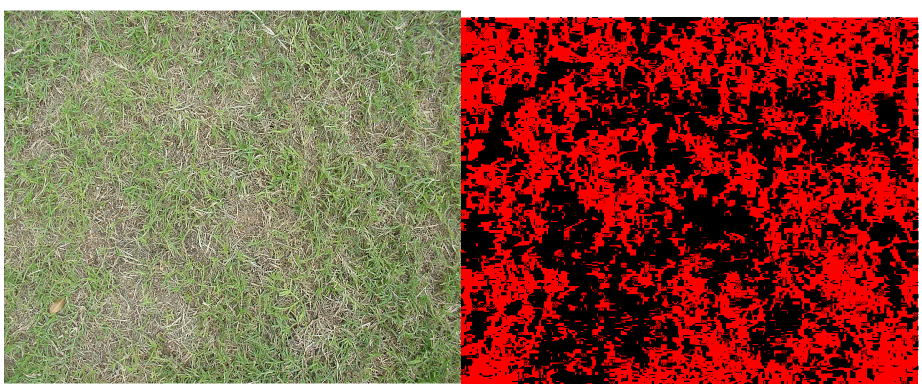
Sahara Pre – Traffic Digital Image of 98% Coverage



Digital Image

Sigma Scan Green Pixel Overlay

Sahara Post – Traffic Digital Image of 50% Coverage



Digital Image

Sigma Scan Green Pixel Overlay

Figure 2. Pre - and post - traffic digital images of Sahara bermudagrass.

0.5 m rotary mower with a bagging attachment. These plots were mowed in the afternoon before the clippings were to be collected the following day. This provided one additional mowing per month for each mowing regime. This ensured that the mowing heights would be the same and the measurements would collect growth in a 24- hour period. This also assisted in the elimination of dried clippings that would be pulled into the samples the following day with the rotary action of the mower. Clippings from the 1.9 cm mowing regime clippings were collected using a 0.5 m reel-type greens mower and clipping basket. This mower was also used on the plots the day before to yield clipping growth in a 24-hour period. The afternoon of the following day, the mowers were used to mow a buffer strip between each sub-sub plot treatment in a north-south direction. This strip was used to start and stop the mower when clippings were being removed from the catch attachments. To collect clippings, the mowers were operated in an east-west direction across each nitrogen fertility subplot. One 9 m by 0.5 m strip was mowed from the center of each 6.69 m^{-2} sub-sub plot. The clippings were emptied into a brown paper bag and placed in a -1.67 ℃ freezer until the fresh weights could be measured the following day. Fresh weights were recorded and the bags were placed in a forced air drying oven for 48 hours at 68.0 ℃. The bags were removed and a dry weight was determined. The samples from June, July, and August were stored to be later analyzed for tissue nitrogen concentration. The samples were initially ground through a 30-mesh sieve then ground through a 60 mesh sieve to ensure homogeneity. Nitrogen concentration by the combustion method was used to analyze tissue samples (Sheldrick, 1986).

Visual quality measurements were taken throughout the growing season. A1 to 9 scale was used with nine indicating perfect turf in terms of uniformity, density, and genetic color (Figure 3). One indicated a complete loss of turfgrass coverage. Five is acceptable for a low budget facility and six would be the minimal acceptable level of a higher budget facility.

After the final traffic simulation measurements, soil penetrometer resistance was measured using a soil penetrometer (Dickey John Soil Compaction Tester). The penetrometer, was used to measure the depth at which 2.07 MPa was reached. This pressure has been established as the level where roots can no longer grow into compacted soils based on research by the United States Department of Agriculture Research Service (USDA-ARS). The 1.9 cm penetrometer tip was inserted into the soil at a rate of 2.54 cm s^{-1} until 2.07 MPa was reached. The depth in inches to this resistance was recorded and converted to centimeters to determine an average level of compaction. Measurements were taken from the traffic areas and adjacent plots not trafficked to differentiate compaction caused by the traffic machine and that potentially caused by normal mower compaction. Penetrometer measurements were used to indicate if compaction caused during the experiment was enough to potentially inhibit root growth.

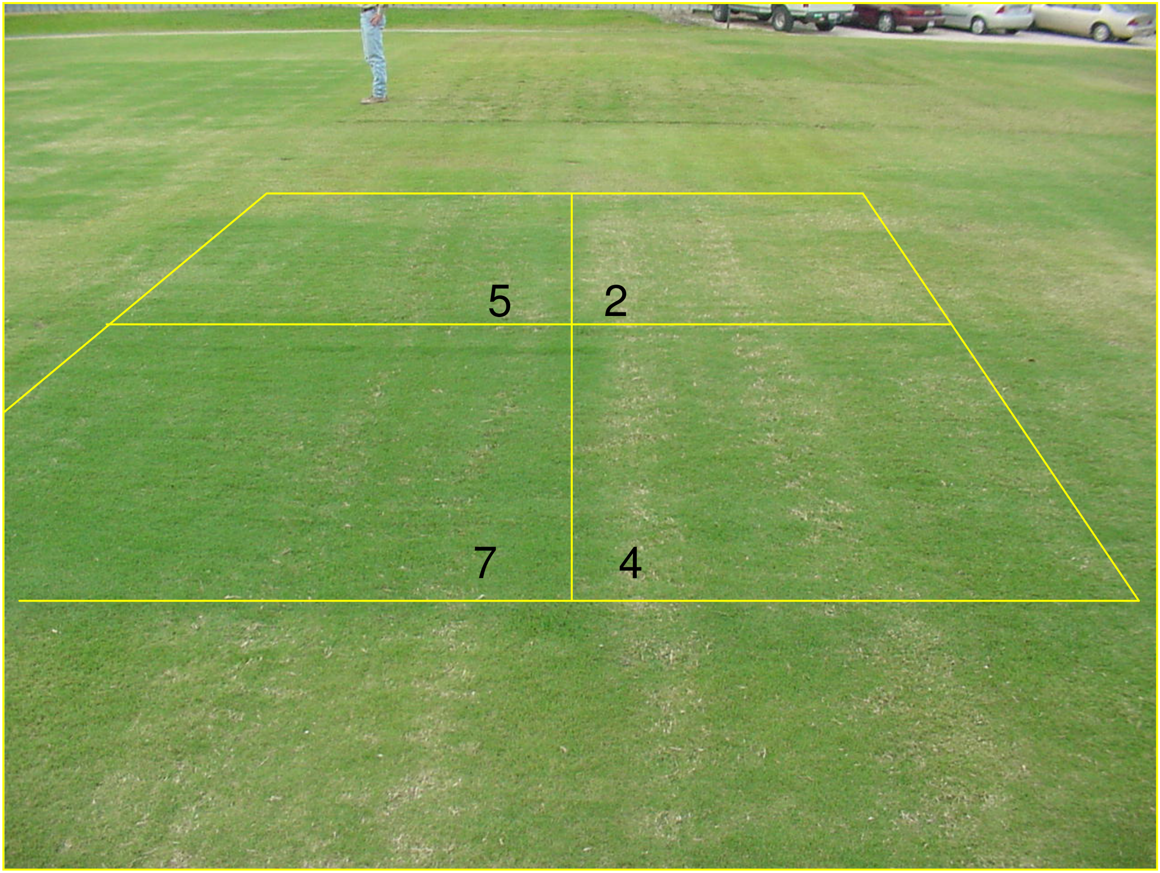


Figure 3. Examples of turfgrass visual quality ratings.

Because differences between events occurred for the traffic events, all data were analyzed separately by date. Analysis of variance (ANOVA) procedures were used to test for treatment effects(SAS Version 8.01, SAS Inst., Cary, NC), and Tukey's Studentized Range Test was used for separation of treatment means when F tests showed significance at the 0.05 probability level. Error terms used for testing main and interactive effects were included in Figure 4.

Source of Variation	Degrees of Freedom
Block	3
Mowing Regime	1
Error A: Block by Mowing Regime	
Cultivar	3
Mowing Regime by Cultivar	3
Error B: Mowing Regime by Block by Cultivar	
Nitrogen	3
Mowing Regime by Nitrogen	3
Cultivar by Nitrogen	9
Mowing Regime by Cultivar by Nitrogen	9
Error C: Mowing Regime by Cultivar by Block by Nitrogen	

Figure 4. Statistical model for ANOVA.

RESULTS AND DISCUSSION

Shoot Density

The mowing regime by cultivar interaction effect on shoot density was significant on two of five sampling dates (Table 2). On all dates, mowing regime two, mowing more frequently at shorter height, had greater shoot density than mowing regime one, mowing less frequently at a taller canopy height. On 27 July, 30 September, and 30 October, shoot density of all cultivars was similar for the less frequent mowing regime (Table 3). However, Tifsport had greater shoot density than the other cultivars on 27 July and Tifsport, GN-1, and Princess had greater shoot density than Sahara on 30 October for the more frequent mowing regime. Mowing regime two promoted greater shoot density than mowing regime one on the other sampling dates. This supports earlier research by that lower at the lower end of the tolerance range increases shoot density (Kim and Beard, 1985). Bermudagrass cultivar also affected shoot density on the other sampling dates. In general, shoot density was greatest for Tifsport, followed by Princess and GN-1, and least for Sahara when averaged across all mowing and N treatments.

The cultivar by nitrogen interaction effect on shoot density was significant on one of the five sampling dates (Table 2). In general, there was not a consistent relationship between increasing nitrogen and shoot density for any of the cultivars across all sampling dates and this was more pronounced on 30 September as indicated by the significant cultivar by nitrogen interaction effect. Applied nitrogen affected shoot density on only two of five sampling dates. On 27 July and 30 September, shoot density increased with nitrogen across all cultivars and mowing regimes.

Table 2. Shoot density as influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen Kg ha^{-1} yr	Shoots per m^2				
			6/23/03	7/27/03	8/30/03	9/30/03	10/30/03
One‡	GN-1	146	13218	2310	3593	4363	5262
One	GN-1	292	10010	4620	3208	4748	4877
One	GN-1	585	10908	6160	3208	6802	4107
One	GN-1	1171	12192	6930	7058	5775	8983
	Cultivar Mean		11582	5005	4267	5422	5807
One	Princess	146	12833	5133	10523	10652	6673
One	Princess	292	12320	7957	7443	4877	11293
One	Princess	585	10138	8213	6802	6930	12577
One	Princess	1171	6930	10138	5647	10267	7187
	Cultivar Mean		10555	7860	7604	8181	9433
One	Sahara	146	3337	4748	1283	7572	4107
One	Sahara	292	5390	6288	898	2823	5518
One	Sahara	585	6417	5133	3080	4492	3208
One	Sahara	1171	3850	3722	4620	5005	7700
	Cultivar Mean		4748	4973	2470	4973	5133
One	Tifsport	146	19635	6288	5647	5647	4363
One	Tifsport	292	17838	8598	6930	8727	4363
One	Tifsport	585	16298	5133	11678	7443	13475
One	Tifsport	1171	14373	7572	5390	11165	7187
	Cultivar Mean		17036	6898	7411	8245	7347
	Height Mean		10981	6184	5438	6705	6930
Two §	GN-1	146	18993	11678	10652	9240	12448
Two	GN-1	292	18480	16170	7443	11807	16298
Two	GN-1	585	25282	14245	14245	16042	29260
Two	GN-1	1171	16555	16170	13860	17710	22073
	Cultivar Mean		19828	14566	11550	13700	20020
Two	Princess	146	20405	17068	17582	23357	19378
Two	Princess	292	20662	17710	15785	17967	18223
Two	Princess	585	20790	16555	17582	14887	24512
Two	Princess	1171	23998	17197	21432	21560	18095
	Cultivar Mean		21464	17133	18095	19443	20052
Two	Sahara	146	13475	10652	10395	15015	12320
Two	Sahara	292	10010	12063	7187	11165	9497
Two	Sahara	585	19892	11678	11165	12320	14630
Two	Sahara	1171	14117	18223	13860	15143	12705
	Cultivar Mean		14373	13154	10652	13411	12288
Two	Tifsport	146	28362	24897	19122	21688	25282
Two	Tifsport	292	24897	30672	20148	27592	22458
Two	Tifsport	585	29773	27592	27335	18352	19250
Two	Tifsport	1171	30800	33495	18223	28105	19250
	Cultivar Mean		28458	29164	21207	23934	21560
	Height Mean		21031	18504	15376	17622	18480

Table 2. Continued.

$MSDMR_{0.05}$†		7873	3693	9297	8581	2289
$MSDC_{0.05}$†		5518	3646	6722	4886	3049
$MSDN_{0.05}$†		4105	3571	6722	2913	4340
Source of Variation	**Df**				**p<f**	
Mowing Regime (MR)	1	*	**	*	*	**
Cultivar (C)	3	***	***	*	**	**
Nitrogen (N)	3	NS	*	NS	*	NS
MR*C	3	NS	**	NS	NS	*
MR*N	3	NS	NS	NS	NS	NS
C*N	9	NS	NS	NS	**	NS
MR*C*N	9	NS	NS	NS	NS	NS

† $TMSDD_{0.05}$, Tukey's Minimum Significant Difference for comparison of effects of mowing regime, grass variety, and nitrogen fertility on shoot density.

NS, Not Significant at the 0.05 probability level.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 3. Mowing regime by cultivar interaction effects on shoot density.

Mowing Regime	Cultivar	Shoots per m^{-2}				
		6/23/03	7/27/03	8/30/03	9/30/03	10/30/03
One ‡	GN-1	11582	5005	4267	5422	5807
	Princess	10555	7860	7604	8181	9433
	Sahara	4748	4973	2470	4973	5133
	Tifsport	17036	6898	7411	8245	7347
$TMSD_{D0.05†}$		5771	NS	4129	NS	NS
Two §	GN-1	19828	14566	11550	13700	20020
	Princess	21464	17133	18095	19443	20052
	Sahara	14373	13154	10652	13411	12288
	Tifsport	28458	29164	21207	23934	21560
$TMSD_{D0.05†}$		5853	5935	6961	6098	7225

†$TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison of cultivar means within columns and mowing regime.

NS, Not Significant at the 0.05 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower.

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower.

Turfgrass Quality Ratings

The mowing regime by cultivar interaction effect on turfgrass quality was significant on only one of the six observation dates (Table 4). On 5 October, all cultivars exhibited a greater turfgrass quality than Sahara for the less frequent and taller mowing regime but for the frequent, shorter mowing regime, turfgrass quality of Sahara was similar to that of Princess and Tifsport.

Mowing regime by nitrogen and cultivar by nitrogen interaction effects were also significant on two of the six sampling dates. On the first two observation dates, turfgrass quality increased to a greater degree with increasing nitrogen for the frequent, shorter mowing regime than for the infrequent, taller mowing regime. The turfgrass quality of Princess increased dramatically with increasing nitrogen yet turfgrass quality of Sahara increased only slightly as applied nitrogen increased. Turfgrass quality of GN-1 and Tifsport also responded positively to increases in applied nitrogen for the first two observation dates.

In general, turfgrass quality was below acceptable levels for the less frequent, taller mowing regime but within an acceptable range for the frequent, shorter mowing regime on all observation dates (Table 5). Superior turfgrass quality for the frequent, shorter than for the infrequent and taller mowing regime was observed on 5 August and 5 September. Greater turfgrass quality was associated with greater shoot density for frequent, shorter compared with the infrequent, taller mowing regime.

Although differences were observed in turfgrass quality among bermudagrass cultivars, no single cultivar consistently produced turfgrass quality that was superior to

Table 4. Turfgrass quality as influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Annual Nitrogen kg ha^{-1}	Visual Quality ±					
			5/5/03	6/4/03	7/8/03	8/5/03	9/5/03	10/5/03
One‡	GN-1	146	3.67	4.67	3.33	3.33	3.67	3.33
One	GN-1	292	3.00	4.00	4.67	4.00	3.67	4.33
One	GN-1	585	4.00	5.00	4.33	4.33	4.33	4.00
One	GN-1	1171	5.00	5.00	5.33	5.00	5.00	5.00
	Cultivar Mean		3.92	4.67	4.42	4.17	4.17	4.17
One	Princess	146	3.33	3.00	3.00	3.00	3.00	3.33
One	Princess	292	3.67	2.67	5.00	4.33	3.67	4.00
One	Princess	585	4.33	4.00	5.00	4.67	4.33	4.67
One	Princess	1171	5.33	5.33	5.67	5.00	5.33	5.33
	Cultivar Mean		4.17	3.75	4.67	4.25	4.08	4.33
One	Sahara	146	2.33	3.33	2.33	2.67	2.67	2.00
One	Sahara	292	2.33	2.00	3.67	2.67	2.33	2.67
One	Sahara	585	3.33	3.33	4.67	3.67	3.00	3.67
One	Sahara	1171	3.00	4.00	5.00	4.33	4.00	4.00
	Cultivar Mean		2.75	3.17	3.92	3.33	3.00	3.08
One	Tifsport	146	3.33	4.00	3.33	3.67	4.00	3.67
One	Tifsport	292	3.67	3.67	4.67	4.00	4.00	3.67
One	Tifsport	585	4.33	4.67	4.67	4.00	3.67	4.33
One	Tifsport	1171	4.67	5.33	5.00	4.33	4.33	4.67
	Cultivar Mean		4.00	4.42	4.42	4.00	4.00	4.08
	Height Mean		3.67	4.00	4.31	3.89	3.78	3.87
Two§	GN-1	146	3.67	4.33	5.67	5.67	6.33	4.33
Two	GN-1	292	4.67	5.33	6.67	6.67	6.67	5.33
Two	GN-1	585	6.00	6.33	5.67	6.33	7.00	6.67
Two	GN-1	1171	5.67	6.67	6.00	7.00	7.67	6.33
	Cultivar Mean		5.00	5.67	6.00	6.42	6.92	5.67
Two	Princess	146	2.67	3.00	4.67	4.67	6.33	3.00
Two	Princess	292	4.67	4.67	6.00	6.00	6.33	4.33
Two	Princess	585	6.33	5.00	6.33	6.00	4.67	5.33
Two	Princess	1171	6.00	6.33	6.33	7.33	7.33	6.33
	Cultivar Mean		4.92	4.75	5.83	6.00	6.17	4.75
Two	Sahara	146	4.33	4.67	4.00	4.33	4.33	3.67
Two	Sahara	292	4.67	4.00	4.67	4.67	4.67	4.67
Two	Sahara	585	5.00	4.67	5.67	5.00	5.00	5.33
Two	Sahara	1171	5.00	5.33	5.67	5.33	5.67	5.33
	Cultivar Mean		4.75	4.67	5.00	4.83	4.92	4.75
Two	Tifsport	146	4.33	6.33	5.67	6.00	6.00	4.67
Two	Tifsport	292	7.00	7.00	6.00	6.67	6.00	4.67
Two	Tifsport	585	5.67	6.67	6.33	7.33	6.00	5.67
Two	Tifsport	1171	6.00	7.33	7.00	6.67	7.00	5.33
	Cultivar Mean		5.75	6.83	6.25	6.67	6.25	5.08
	Height Mean		5.10	5.48	5.77	5.98	6.06	5.06

Table 4. Continued.

$MSDMR_{0.05†}$		1.51	0.94	1.59	0.47	0.56	1.77
$MSDC_{0.05†}$		1.78	0.83	0.68	0.64	0.73	0.62
$MSDN_{0.05†}$		0.61	0.59	0.53	0.61	0.74	0.84

Source of Variation	df			p>f			
Mowing Regime (MR)	1	NS	*	NS	**	**	NS
Cultivar (C)	3	NS	***	**	***	***	**
Nitrogen (N)	3	***	***	***	***	***	***
MR*C	3	NS	NS	NS	NS	NS	*
MR*N	3	*	*	NS	NS	NS	NS
C*N	9	*	*	NS	NS	NS	NS
MR*C*N	9	NS	NS	NS	NS	NS	NS

† TMSDD0.05, Tukey's Minimum Significant Difference for comparison
of effects of mowing regime, cultivar, and nitrogen fertility on visual quality.

NS, Not Significant at the 0.05 probability level.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

±Scale of 1-9 with 9.0 the highest and 5.0 Minimal Acceptable Level

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 5. Main effects of mowing regime, bermudagrass cultivar, and annual applied nitrogen on turfgrass quality.

Treatments	Visual Quality ±					
	5/5/03	6/4/03	7/8/03	8/5/03	9/5/03	10/5/03
Mowing Regime						
One‡	3.71	4.00	4.35	3.94	3.81	3.92
Two§	5.10	5.48	5.77	5.98	6.06	5.06
$TMSDMR_{0.05}$†	*	*	0.43	0.43	0.48	*
Cultivar						
GN-1	4.46	5.17	5.21	5.29	5.54	4.92
Princess	4.54	4.25	5.25	5.13	5.13	4.54
Sahara	3.75	3.92	4.46	4.08	3.96	3.92
Tifsport	4.88	5.63	5.33	5.33	5.13	4.58
$TMSDC_{0.05}$∞	*	*	NS	1.06	1.17	NS
N kg ha^{-1}						
146	3.46	4.17	4.00	4.17	4.54	3.50
292	4.21	4.17	5.17	4.88	4.67	4.21
585	4.88	4.96	5.33	5.17	4.75	4.96
1171	5.08	5.67	5.75	5.63	5.79	5.29
$TMSDN_{0.05}$∂	*	*	0.84	1.06	1.19	0.92

†$TMSDMR_{0.05,}$ Tukey's Minimum Significant Difference for comparison of mowing regime means within columns.

∞$TMSDC_{0.05,}$ Tukey's Minimum Significant Difference for comparison of bermudagrass cultivar means within columns.

∂$TMSDN_{0.05,}$ Tukey's Minimum Significant Difference for comparison of annual applied nitrogen means within columns.

NS, Not Significant at the 0.05 probability level.

* No Main Effect Due to Significant Interaction Effect.

±Scale of 1-9 with 9.0 the highest and 5.0 Minimal Acceptable Level

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

other cultivars (Table 5). However, when averaged across all mowing and nitrogen treatments, Sahara had turfgrass quality that was below an acceptable level on all observation dates. Tifsport and GN-1 had acceptable turfgrass quality on four of the six and Princess had acceptable quality on three of the six observation dates.

Across all mowing regimes and cultivars, turfgrass quality increased with increasing nitrogen for observation dates in July through October (Table 5). When averaged across all mowing regimes and cultivars, excessive (585 and 1171 kg N ha^{-1}) amounts of nitrogen were required to produce acceptable turfgrass quality on almost every observation date. However, when used in combination with the frequent and shorter mowing regime, most cultivars, with the exception of Sahara, produced acceptable turfgrass quality when modest (146 and 292 kg N ha^{-1}) annual nitrogen amounts were applied (Table 4).

Pre - Traffic Turfgrass Coverage

Digital image analysis was used to quantify green canopy coverage prior to traffic. The mowing regime by cultivar by nitrogen interaction was significant on one date. The mowing regime by cultivar interaction effect was significant on two of the eight observation dates (Table 6). On 4 August, Sahara had 8 to 10 and on 13 October, 10 to 22 percent less coverage than other cultivars for the infrequent, taller mowing regime. Yet, cultivars had similar coverage under the frequent, shorter mowing regime on 4 August and 13 October. The mowing regime by nitrogen interaction effect on pre-traffic green canopy coverage was significant on four of the eight observation dates

(Table 6). For the frequent, shorter mowing regime, percent cover was similar among N treatments on 16 June, 1 July, 4 August, and 2 September (Table 7). On these same dates, however, percent coverage generally increased with increasing nitrogen in conjunction with the infrequent, taller regime. Although nitrogen influenced pre-traffic green canopy coverage on five of the eight observation dates, coverage generally increased more with increasing nitrogen in conjunction with the infrequent, taller than with the frequent, shorter mowing regime during mid-June through early-September (Table 6). On 29 September and 13 October, pre-traffic coverage increased with nitrogen across all cultivars and mowing regimes. Based on these data, mowing regime had a primary influence on pre-traffic coverage in early summer whereas nitrogen had less of an effect, yet nitrogen had a more substantial influence on pre-traffic coverage later in the growing season. Growth rates of all cultivars slowed in the fall. Mowing had a greater influence on maintaining density in the early months of peak growth. As growth slowed, the mowing regime influence was reduced and the influence of nitrogen was more evident. The danger of increasing fall nitrogen is the possible reduction in carbohydrate accumulation resulting in a decreased level of winter hardiness (Carrow et. al. 2001).

Table 6. Pre - traffic percent coverage values influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen kg ha^{-1} yr	Pre - Traffic Percent Coverage Values							
			6/1/03	6/16/03	7/1/03	7/21/03	8/4/03	9/2/03	9/29/03	10/13/03
One‡	GN-1	146	98.33	97.00	96.00	85.67	92.00	95.67	84.67	81.00
One	GN-1	292	98.33	95.00	97.00	85.33	95.33	96.33	84.33	86.00
One	GN-1	585	98.33	96.67	97.00	81.33	96.67	98.00	89.00	86.33
One	GN-1	1171	96.67	98.67	99.00	75.00	97.33	96.33	88.33	90.33
	Cultivar Mean		97.92	96.83	97.25	81.83	95.33	96.58	86.58	85.92
One	Princess	146	98.67	97.33	90.67	86.00	91.00	92.33	74.33	66.00
One	Princess	292	98.33	95.00	98.00	85.67	96.00	94.33	71.33	86.00
One	Princess	585	98.33	98.00	98.33	85.67	95.67	97.00	81.67	85.33
One	Princess	1171	97.67	99.33	99.00	93.00	98.33	98.00	85.67	91.67
	Cultivar Mean		98.25	97.42	96.50	87.58	95.25	95.42	78.25	82.25
One	Sahara	146	90.67	85.67	72.67	58.67	70.33	91.00	61.67	55.33
One	Sahara	292	90.00	80.00	85.67	68.67	89.33	86.00	58.33	63.33
One	Sahara	585	95.00	94.00	89.33	75.67	94.67	92.33	70.67	70.33
One	Sahara	1171	92.33	96.33	90.67	78.67	94.33	91.00	69.00	65.00
	Cultivar Mean		92.00	89.00	84.58	70.42	87.17	90.08	64.92	63.50
One	Tifsport	146	95.33	97.33	93.33	87.00	96.33	95.33	70.67	61.67
One	Tifsport	292	97.00	97.33	98.67	84.67	97.00	95.67	78.33	75.00
One	Tifsport	585	96.00	98.67	97.33	87.00	98.67	97.00	79.00	80.00
One	Tifsport	1171	96.33	99.00	99.00	75.67	99.00	97.67	79.67	76.33
	Cultivar Mean		96.17	98.08	97.08	83.58	97.75	96.42	76.92	73.25
	Height Mean		96.08	95.33	93.85	80.85	93.87	94.62	76.67	76.23
Two§	GN-1	146	98.67	97.33	92.67	93.67	98.00	96.67	80.00	72.67
Two	GN-1	292	98.33	97.00	93.33	90.33	97.67	96.67	76.00	83.00
Two	GN-1	585	98.67	98.00	91.33	93.33	98.33	97.00	83.00	88.67
Two	GN-1	1171	98.67	98.33	90.00	88.33	97.67	96.67	83.00	87.33
	Cultivar Mean		98.58	97.67	91.83	91.42	97.92	96.75	80.50	82.92
Two	Princess	146	97.00	94.67	81.00	76.67	91.33	94.33	83.00	80.00
Two	Princess	292	97.67	88.33	88.67	90.00	95.67	96.33	78.33	85.33
Two	Princess	585	98.00	94.33	80.67	80.00	98.00	92.00	84.33	88.00
Two	Princess	1171	98.67	92.67	84.67	76.33	95.33	97.67	83.33	96.00
	Cultivar Mean		97.83	92.50	83.75	80.75	95.08	95.08	82.25	87.33
Two	Sahara	146	98.33	92.67	84.00	84.33	95.33	93.33	69.67	69.00
Two	Sahara	292	97.67	94.00	89.00	91.00	95.67	94.67	80.67	86.33
Two	Sahara	585	97.67	94.33	84.67	83.67	95.00	92.67	83.33	89.33
Two	Sahara	1171	98.33	95.67	86.67	91.67	95.33	94.00	86.00	91.00
	Cultivar Mean		98.00	94.17	86.08	87.67	95.33	93.67	79.92	83.92
Two	Tifsport	146	98.67	96.33	91.00	82.67	94.67	96.33	77.00	79.33
Two	Tifsport	292	97.33	95.67	93.67	85.67	96.33	96.33	79.67	85.33
Two	Tifsport	585	99.00	96.00	89.33	72.67	94.33	94.67	86.67	86.33
Two	Tifsport	1171	97.00	91.67	92.67	82.00	95.33	95.67	85.67	88.00
	Cultivar Mean		98.00	94.92	91.67	80.75	95.17	95.75	82.25	84.75
	Height Mean		98.10	94.81	88.33	85.15	95.87	95.31	81.23	84.73

Table 6. Continued.

$MSDMR_{0.05†}$		1.65	2.86	3.59	19.59	7.67	1.94	4.63	13.00
$MSDC_{0.05†}$		4.12	5.06	6.74	18.43	4.33	3.19	18.73	8.91
$MSDN_{0.05†}$		1.40	2.76	7.56	5.95	2.58	1.99	6.07	6.32
Source of Variation	Df				p<f				
Mowing Regime (MR)	1	*	NS	*	NS	NS	NS	NS	NS
Cultivar ©	3	NS	*	**	NS	*	**	NS	**
Nitrogen (N)	3	NS	**	***	NS	***	NS	**	***
MR*C	3	NS	NS	NS	NS	*	NS	NS	*
MR*N	3	NS	*	***	NS	***	*	NS	NS
C*N	9	NS	NS	*	NS	**	NS	NS	NS
MR*C*N	9	NS	NS	NS	NS	***	NS	NS	NS

†$TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison of effects of mowing regime, cultivar, and nitrogen on pre - traffic percent coverage.
NS, Not Significant at the 0.05 probability level.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower
§ Mowing regime two is three times weekly mowing at 1.9 cm with a reel mower

Table 7. Pre - traffic percent coverage values influenced by mowing regime and annual applied nitrogen interactions.

Mowing Regime	Nitrogen kg ha^{-1} yr	Pre - Traffic Percent Coverage Values							
		6/1/03	6/16/03	7/1/03	7/21/03	8/4/03	9/2/03	9/29/03	10/13/03
	146	95.75	94.33	88.17	79.33	87.42	93.58	72.83	66.00
	292	95.92	91.83	94.83	81.08	94.42	93.08	73.08	77.58
One‡	585	96.92	96.83	95.50	82.42	96.42	96.08	80.08	80.50
	1171	95.75	98.33	96.92	80.58	97.25	95.75	80.67	80.83
$TMSD_{D0.05†}$		NS	5.96	7.48	NS	7.59	NS	NS	13.84
	146	98.17	95.25	87.17	84.33	94.83	95.17	77.42	75.25
	292	97.75	93.75	91.17	89.25	96.33	96.00	78.67	85.00
Two§	585	98.33	95.67	86.50	82.42	96.42	94.08	84.33	88.08
	1171	98.17	94.58	88.50	84.58	95.92	96.00	84.50	90.58
$TMSD_{D0.05†}$		NS	NS	NS	NS	NS	NS	NS	8.04

†$TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison of mowing regime means within columns and nitrogen.
NS, Not Significant at the 0.05 probability level.
‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower
§ Mowing regime two is three times weekly mowing at 1.9 cm with a reel mower

Post -Traffic Turfgrass Coverage

Post-traffic turfgrass canopy coverage was estimated as the percentage of green canopy remaining following a simulated traffic event (Table 8). The mowing regime by cultivar by nitrogen effect was significant on only one of eight observation dates as was the cultivar by nitrogen interaction effect. The mowing regime by cultivar interaction effect was significant on two of the last three observation dates. On 5 August, Sahara had less post-traffic coverage than other cultivars in conjunction with the infrequent, taller mowing regime. Yet, in conjunction with the frequent, shorter mowing regime, Sahara had post-traffic coverage similar to other cultivars. In general, Sahara had better post-traffic coverage in conjunction with the frequent, shorter than with the infrequent, taller mowing regime for all observation dates (Table 9). On 30 September, Sahara, had post-traffic coverage similar to Princess and Tifsport but not GN-1 when mowed taller and infrequently. GN-1 had better post-traffic coverage than all other cultivars in conjunction with the infrequent, taller mowing regime on 30 September (Table 8 and 9). In conjunction with the frequent, shorter mowing regime, post-traffic coverage for GN-1 was similar to other cultivars. In general, GN-1 had better post-traffic coverage in June and early July when used in conjunction with the frequent shorter rather than the infrequent taller mowing regime.

In August and late September, GN-1 had less post-traffic coverage in conjunction with the frequent, shorter than with the infrequent taller mowing regime. On 2 July and 5 August, the mowing regime by nitrogen interaction effect was significant (Table 8). On these two dates, post-traffic coverage substantially increased with nitrogen in conjunction with the infrequent taller mowing regime but slightly increased with nitrogen with the frequent shorter mowing regime. The main effect of nitrogen was significant on these two dates as well as on 17 June and 30 September. In general, post-traffic coverage increased with increasing nitrogen although shoot density did not. In June and July, Sahara had less post-traffic coverage than the other cultivars but was similar to other cultivars at other observation dates depending on mowing regime and annual applied nitrogen (Table 8). Sahara had the least shoot density compared to other cultivars, but shoot density of Sahara, and other cultivars, was influenced by mowing regime and nitrogen and thus these factors influenced the relative post-traffic coverage among cultivars.

Table 8. Post-traffic turfgrass canopy coverage influenced by mowing regime, bermudagrass cultivars, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen kg ha^{-1} yr	Post-Traffic Percent Coverage Values						
			6/2/03	6/17/03	7/2/03	7/22/03	8/5/03	9/3/03	9/30/03
One‡	GN-1	146	91.00	84.33	84.00	54.00	84.00	80.00	82.00
One	GN-1	292	93.33	81.33	88.00	54.67	90.67	83.67	83.33
One	GN-1	585	89.00	83.67	80.67	49.33	90.33	84.00	83.33
One	GN-1	1171	84.00	82.33	93.00	62.33	95.33	88.00	88.67
	Cultivar Mean		89.33	82.92	86.42	55.08	90.08	83.92	84.33
One	Princess	146	96.00	80.33	73.67	58.00	61.33	71.33	54.33
One	Princess	292	95.00	81.00	88.67	74.67	80.33	78.33	56.67
One	Princess	585	96.00	84.67	93.00	78.00	88.00	87.67	63.67
One	Princess	1171	96.00	89.33	95.00	82.67	90.67	87.33	64.67
	Cultivar Mean		95.75	83.83	87.58	73.33	80.08	81.17	59.83
One	Sahara	146	79.00	40.67	54.67	31.33	44.67	75.33	50.00
One	Sahara	292	76.00	36.00	65.67	33.00	55.00	69.00	45.00
One	Sahara	585	78.00	52.00	70.67	41.67	75.00	74.00	51.67
One	Sahara	1171	80.33	59.00	75.33	37.67	77.67	73.00	47.67
	Cultivar Mean		78.33	46.92	66.58	35.92	63.08	72.83	48.58
One	Tifsport	146	96.33	83.00	89.33	65.33	87.00	79.67	37.67
One	Tifsport	292	95.00	81.67	94.67	72.67	92.33	85.67	46.00
One	Tifsport	585	94.00	87.00	94.67	75.00	95.00	86.00	52.33
One	Tifsport	1171	95.67	85.33	96.67	58.00	95.00	85.33	42.67
	Cultivar Mean		95.25	84.25	93.83	67.75	92.33	84.17	44.67
	Height Mean		89.67	74.48	83.60	58.02	81.40	80.52	59.35
Two§	GN-1	146	94.67	82.00	93.33	59.00	83.00	89.33	57.00
Two	GN-1	292	94.33	83.33	94.00	58.00	82.33	86.00	56.33
Two	GN-1	585	96.33	81.33	95.67	71.67	84.33	74.00	65.00
Two	GN-1	1171	95.67	85.33	94.67	53.67	82.00	85.00	57.33
	Cultivar Mean		95.25	83.00	94.42	60.58	82.92	83.58	58.92
Two	Princess	146	95.33	89.67	83.67	56.67	85.00	87.00	75.00
Two	Princess	292	96.33	84.33	96.00	57.33	86.33	88.67	79.33
Two	Princess	585	98.00	90.67	93.00	69.00	91.00	87.33	76.00
Two	Princess	1171	97.33	88.00	96.67	40.33	93.00	93.67	86.00
	Cultivar Mean		96.75	88.17	92.33	55.83	88.83	89.17	79.08
Two	Sahara	146	91.67	62.33	80.33	49.00	84.00	70.67	67.67
Two	Sahara	292	80.67	59.00	81.33	65.00	86.67	75.00	75.33
Two	Sahara	585	85.67	61.00	80.00	65.33	84.00	75.00	72.67
Two	Sahara	1171	84.33	75.00	80.33	66.00	85.67	71.00	77.67
	Cultivar Mean		85.58	64.33	80.50	61.33	85.08	72.92	73.33
Two	Tifsport	146	98.00	89.33	93.00	54.67	79.67	78.00	73.67
Two	Tifsport	292	99.00	90.00	97.00	61.00	83.33	74.33	76.00
Two	Tifsport	585	98.33	93.67	95.67	55.33	82.00	78.67	81.67
Two	Tifsport	1171	98.33	90.67	97.67	65.00	83.00	83.67	82.67
	Cultivar Mean		98.42	90.92	95.83	59.00	82.00	78.67	78.50
	Height Mean		94.00	81.60	90.77	59.19	84.71	81.08	72.46

Table 8. Continued.

$MSDMR_{0.05†}$		2.67	28.59	26.53	7.22	13.88	42.80	23.71
$MSDC_{0.05†}$		7.20	19.52	9.47	40.24	13.72	19.22	23.45
$MSDN_{0.05†}$		3.61	5.38	3.74	9.02	5.66	6.90	6.09

Source of Variation	Df				p<f			
Mowing Regime (MR)	1	*	NS	NS	NS	NS	NS	NS
Cultivar (C)	3	***	**	***	NS	*	NS	NS
Nitrogen (N)	3	NS	**	***	NS	***	NS	*
MR*C	3	NS	NS	NS	NS	*	NS	*
MR*N	3	NS	NS	*	NS	***	NS	NS
C*N	9	NS	NS	*	NS	NS	NS	NS
MR*C*N	9	NS	NS	NS	*	NS	NS	NS

†$TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison
of influence of mowing regime, cultivar, and nitrogen on post - traffic coverage.
NS, Not Significant at the 0.05 probability level.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower
§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 9. Post-traffic turfgrass canopy coverage as influenced by mowing regime and cultivar interaction effects.

Mowing Regime	Cultivar	Canopy Coverage After Traffic						
		6/2/03	6/17/03	7/2/03	7/22/03	8/5/03	9/3/03	9/30/03
	GN-1	89.33	82.92	86.42	55.08	90.08	83.92	84.33
	Princess	95.75	83.83	87.58	73.33	80.08	81.17	59.83
One‡	Sahara	78.33	46.92	66.58	35.92	63.08	72.83	48.58
	Tifsport	95.25	84.25	93.83	67.75	92.33	84.17	44.67
$TMSD_{D0.05}$†		6.46	12.76	9.50	23.52	13.98	NS	14.28
	GN-1	95.25	83.00	94.42	60.58	82.92	83.58	58.92
	Princess	96.75	88.17	92.33	55.83	88.83	89.17	79.08
Two§	Sahara	85.58	64.33	80.50	61.33	85.08	72.92	73.33
	Tifsport	98.42	90.92	95.83	59.00	82.00	78.67	78.50
$TMSD_{D0.05}$†		4.84	11.51	6.92	NS	NS	13.902	13.33

†$TMSD_{D0.05}$, Tukey's Minimum Significant Difference for comparison of cultivar means within columns and mowing regime.

NS, Not Significant at the 0.05 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Traffic Injury

Traffic injury was determined by the percentage decrease in pre-traffic and post-traffic turfgrass canopy coverage (Table 10). The mowing regime by nitrogen interaction effect was significant on one of the observation dates. The mowing regime by cultivar interaction effect was significant on two of the observation dates. On 5 August, greater injury was observed for Sahara than for Tifsport and GN-1 in conjunction with the infrequent, taller mowing regime, but injury was similar among cultivars when the frequent, shorter mowing regime was used (Tables 10 and 11). On 30 September, however, injury from traffic for Sahara was greater than for GN-1, similar to Princess, and less than for Tifsport in conjunction with the infrequent, taller mowing regime. When the frequent, shorter mowing regime was applied, Sahara had similar injury from traffic as Princess and Tifsport but less than that of GN-1. It should be noted that increased mower scalping occurred with Tifsport in these months due the upright growth habit with green leaf tissue only in the top of the turf canopy. Princess and GN-1 have a more prostrate growth habit that prevented mower scalping and produced leaves along the prostrate stolons. This is important when percent coverage measurements are made using green tissue and tissue is removed possibly by mowing rather than traffic. Cultivar influenced traffic injury on three of the initial observations dates as well (Tables 10 and 12). In June and early July, Sahara exhibited greater injury from traffic than all other cultivars. On 5 August, Sahara exhibited greater injury than Tifsport but had similar injury from traffic as GN-1 and Princess. Across all cultivar and nitrogen treatments,

Table 10. Traffic injury as influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen kg ha^{-1} yr	Percent Decrease in Turfgrass Coverage						
			6/2/03	6/17/03	7/2/03	7/22/03	8/5/03	9/3/03	9/30/03
One‡	GN-1	146	-7.43	-13.05	-12.45	-37.93	-8.78	-16.71	-3.22
One	GN-1	292	-5.08	-14.43	-9.24	-38.96	-4.76	-13.13	-0.79
One	GN-1	585	-9.47	-13.45	-17.04	-41.63	-6.55	-14.28	-6.30
One	GN-1	1171	-13.05	-16.55	-6.06	-18.92	-2.00	-8.57	1.07
	Grass mean		-8.76	-14.37	-11.20	-34.36	-5.52	-13.17	-2.31
One	Princess	146	-2.70	-17.62	-19.41	-34.16	-33.73	-23.83	-28.36
One	Princess	292	-3.39	-15.36	-9.56	-12.61	-16.29	-17.71	-20.49
One	Princess	585	-2.37	-13.53	-5.43	-8.16	-7.97	-9.62	-21.59
One	Princess	1171	-1.70	-10.09	-4.05	-11.34	-7.80	-10.96	-24.40
	Grass mean		-2.54	-14.15	-9.61	-16.57	-16.45	-15.53	-23.71
One	Sahara	146	-12.54	-52.89	-24.56	-45.00	-36.86	-17.23	-20.66
One	Sahara	292	-13.61	-53.84	-23.33	-47.46	-38.75	-19.83	-25.44
One	Sahara	585	-17.88	-44.68	-20.87	-44.22	-20.79	-20.00	-28.53
One	Sahara	1171	-12.63	-38.49	-16.92	-51.73	-18.25	-19.71	-31.72
	Grass mean		-14.16	-47.48	-21.42	-47.10	-28.66	-19.19	-26.59
One	Tifsport	146	1.16	-14.76	-4.22	-25.42	-9.72	-16.24	-43.62
One	Tifsport	292	-2.11	-16.10	-4.05	-13.44	-4.81	-10.40	-40.01
One	Tifsport	585	-2.13	-11.86	-2.74	-13.54	-3.71	-11.39	-32.38
One	Tifsport	1171	-0.69	-13.87	-2.36	-23.19	-4.04	-12.67	-45.86
	Grass mean		-0.94	-14.15	-3.34	-18.90	-5.57	-12.68	-40.47
	Height mean		-6.60	-22.54	-11.39	-29.23	-14.05	-15.14	-23.27
Two§	GN-1	146	-4.07	-15.65	-0.08	-36.96	-15.36	-7.54	-27.78
Two	GN-1	292	-4.10	-13.93	-0.75	-37.49	-15.67	-11.08	-26.75
Two	GN-1	585	-2.38	-16.95	-0.48	-23.11	-14.28	-24.59	-21.34
Two	GN-1	1171	-3.04	-13.16	-0.52	-39.48	-16.00	-12.09	-31.52
	Grass mean		-3.40	-14.92	-0.46	-34.26	-15.33	-13.83	-26.85
Two	Princess	146	-1.64	-5.14	-4.68	-25.54	-6.81	-7.83	-9.90
Two	Princess	292	-1.33	-3.10	-8.59	-36.58	-9.72	-8.04	-2.67
Two	Princess	585	0.01	-3.93	-18.59	-12.50	-7.14	-5.06	-9.97
Two	Princess	1171	-1.35	-5.16	-14.53	-48.75	-2.40	-4.09	-3.55
	Grass mean		-1.08	-4.33	-11.60	-30.84	-6.52	-6.26	-6.52
Two	Sahara	146	-6.77	-32.85	-4.69	-41.25	-11.76	-24.86	-2.77
Two	Sahara	292	-17.49	-37.56	-8.70	-28.26	-9.35	-20.73	-6.58
Two	Sahara	585	-12.28	-35.64	-5.77	-19.40	-11.57	-19.05	-12.55
Two	Sahara	1171	-14.26	-21.70	-7.86	-27.93	-10.24	-24.12	-9.81
	Grass mean		-12.70	-31.94	-6.75	-29.21	-10.73	-22.19	-7.93
Two	Tifsport	146	-0.66	-7.38	-2.16	-35.91	-15.89	-19.08	-3.74
Two	Tifsport	292	1.74	-5.99	-3.62	-30.53	-13.61	-22.91	-4.26
Two	Tifsport	585	-0.67	-2.45	-7.26	-27.49	-12.54	-16.80	-5.80
Two	Tifsport	1171	1.40	-1.11	-5.42	-22.94	-13.58	-12.64	-3.28
	Grass mean		0.45	-4.23	-4.62	-29.22	-13.91	-17.86	-4.27
	Height mean		-4.18	-13.86	-5.86	-30.88	-11.62	-15.03	-11.39

Table 10. Continued.

$MSD_{0.05MR†}$		1.45	27.63	33.44	27.03	15.31	43.58	22.31
$MSD_{0.05C†}$		9.71	21.51	9.90	43.61	13.14	19.64	27.31
$MSD_{0.05N†}$		4.35	5.26	4.46	9.97	5.73	6.65	5.49

Source of Variation	df				p>f			
Mowing Regime (MR)	1	*	NS	NS	NS	NS	NS	NS
Cultivar (C)	3	**	**	**	NS	*	NS	NS
Nitrogen (N)	3	NS	NS	**	*	**	NS	NS
MR*C	3	NS	NS	NS	NS	*	NS	*
MR*N	3	NS	NS	NS	NS	*	NS	NS
C*N	9	NS	NS	NS	NS	NS	NS	NS
MR*C*N	9	NS	NS	NS	NS	NS	NS	NS

† TMSDD0.05, Tukey's Minimum Significant Difference for comparison of effects of mowing regime, cultivar, and nitrogen on injury values.

NS, Not Significant at the 0.05 probability level.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm with a rotary mower

§ Mowing regime two is three times weekly mowing at 1.9 cm with a reel mower

Table 11. Traffic injury influenced by mowing regime and cultivar interaction effects.

Mowing Regime	Cultivar	Percent Decrease in Turfgrass Coverage						
		6/2/03	6/17/03	7/2/03	7/22/03	8/5/03	9/3/03	9/30/03
One ‡	GN-1	-8.76	-14.37	-11.20	-34.36	-5.52	-13.17	-2.31
	Princess	-2.54	-14.15	-9.61	-16.57	-16.45	-15.53	-23.71
	Sahara	-14.16	-47.48	-21.42	-47.10	-28.66	-19.19	-26.59
	Tifsport	-0.94	-14.15	-3.34	-18.90	-5.57	-12.68	-40.47
	TMSDD0.05†	8.68	12.71	6.92	27.43	11.98	NS	16.24
Two §	GN-1	-3.40	-14.92	2.87	-34.26	-15.33	-13.75	-26.85
	Princess	-1.08	-4.33	11.58	-30.84	-6.52	-6.26	-3.41
	Sahara	-12.70	-31.94	-6.75	-29.18	-10.73	-22.19	-7.93
	Tifsport	0.45	-4.23	4.62	-29.22	-13.80	-17.86	-4.27
	TMSDD0.05†	4.84	12.27	8.83	NS	NS	14.46	14.01

† $TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison of mowing regimes within columns and cultivars.
NS, Not Significant at the 0.05 probability level.
‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times per week mowing at 1.9 cm with a reel mower

Table 12. Main effect of bermudagarss cultivar on traffic injury.

Cultivar	Percent Decrease in Turfgrass Coverage						
	6/2/03	6/17/03	7/2/03	7/22/03	8/5/03	9/3/03	9/30/03
GN-1	-6.08	-14.65	-4.16	-34.31	-10.43	-13.46	-14.58
Princess	-1.81	-9.24	0.99	-23.70	-11.48	-10.89	-13.56
Sahara	-13.43	-39.71	-14.09	-38.14	-19.70	-20.69	-17.26
Tifsport	-0.24	-9.19	0.64	-24.06	-9.69	-15.27	-22.37
$TMSD_{D0.05†}$	4.84	9.95	9.04	NS	NS	NS	NS

†$TMSD_{D0.05}$, Tukey's Minimum Significant Difference for comparison of cultivar means within columns.
NS, Not Significant at the 0.05 probability level.

mowing regime influenced traffic injury on one of the seven observation dates (Table 10). On 2 June, the infrequent, taller mowing regime had greater traffic injury than the frequent, shorter mowing regime. This same trend was observed on 17 June, 2 July, and 30 September. Annual applied nitrogen influenced traffic injury on three of the seven observation dates (Table 10 and 13). While significant, increasing annual applied nitrogen did not decrease the percent coverage values of bermudagrass.

Table 13. Influence of annual applied nitrogen on traffic injury.

Nitrogen kg ha^{-1} yr	Percent Decrease in Turfgrass Coverage						
	6/2/03	6/17/03	7/2/03	7/22/03	8/5/03	9/3/03	9/30/03
146	-4.33	-19.92	-7.22	-35.26	-17.36	-16.67	-17.51
292	-5.67	-20.04	-5.24	-30.67	-14.12	-15.48	-15.21
585	-5.90	-17.81	-2.66	-23.76	-10.57	-15.06	-17.31
1171	-5.67	-15.02	-1.51	-30.54	-9.24	-13.11	-17.75
$TMSDN_{D0.05†}$	NS	NS	4.46	9.97	5.03	NS	NS

†$TMSD_{D0.05}$, Tukey's Minimum Significant Difference for comparison of nitrogen means within columns.

NS, Not Significant at the 0.05 probability level.

Tissue Nitrogen Content

A cultivar by nitrogen interaction effect occurred on one of the three sampling dates (Table 14). On 20 June, Sahara, Princess, and GN-1 had higher tissue nitrogen as annual nitrogen levels increased (Table 15). Bermudagrass tissue nitrogen levels currently are considered to be in the adequate range with levels between 3 and 5 g kg^{-1} (Carrow et al, 2001). Nitrogen applied influenced the tissue nitrogen concentration on all three dates (Table 16). The excessive nitrogen treatment had the highest tissue nitrogen content. The 585 kg ha^{-1} yr^{-1} treatment was no different from 1171 kg ha^{-1} yr^{-1} on 25 July and 28 August. The minimal nitrogen treatment was in the lowest group on all three dates. The 1171 kg ha^{-1} yr^{-1} was the only treatment to maintain a tissue nitrogen level above 3% on all three dates. The 585 kg ha^{-1} yr^{-1} treatment maintained tissue nitrogen levels above 3% in June and August. Traffic injury values did not indicate that any fertility level decreased the traffic tolerance of bermudagrass. Over the wide range of nitrogen fertility used in this experiment, there was not a wide range of difference between percent total nitrogen in the tissue. Mowing regime analysis indicated that the lower, more frequent treatment had a greater percentage of total nitrogen than the higher, less frequent mowing regime on all dates (Table 15). One possibility for this is that the rotary mower used for clipping collection for mowing regime two may have removed more dead leaves from the lower canopy than the front catch reel type mower used to collect mowing regime two. The plots were mowed with these mowers the day before to remove any loose material and ensure the mowing height would be the same the

Table 14. Percent total tissue nitrogen as influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen kg ha^{-1} yr	Percent Total Nitrogen g kg^{-1}		
			6/20/03	7/25/03	8/28/03
One‡	GN-1	146	2.95	2.41	2.76
One	GN-1	292	2.86	2.53	2.47
One	GN-1	585	2.88	2.55	2.83
One	GN-1	1171	3.39	2.69	3.32
	Cultivar Mean		3.02	2.54	2.85
One	Princess	146	2.41	2.17	2.11
One	Princess	292	2.45	2.34	2.60
One	Princess	585	2.81	2.37	2.93
One	Princess	1171	3.18	2.63	3.27
	Cultivar Mean		2.71	2.38	2.73
One	Sahara	146	2.87	2.25	2.30
One	Sahara	292	2.47	2.26	2.31
One	Sahara	585	3.06	2.39	2.71
One	Sahara	1171	3.50	2.59	3.13
	Cultivar Mean		2.97	2.37	2.61
One	Tifsport	146	3.08	2.37	2.40
One	Tifsport	292	3.18	2.56	2.67
One	Tifsport	585	3.12	2.52	2.99
One	Tifsport	1171	3.19	2.68	3.26
	Cultivar Mean		3.14	2.53	2.83
	Height Mean		2.96	2.46	2.75
Two§	GN-1	146	3.19	2.87	2.98
Two	GN-1	292	3.22	3.07	3.31
Two	GN-1	585	3.21	3.22	3.62
Two	GN-1	1171	3.96	3.55	3.86
	Cultivar Mean		3.39	3.18	3.44
Two	Princess	146	2.86	2.57	2.75
Two	Princess	292	3.09	2.90	2.84
Two	Princess	585	3.29	2.83	3.29
Two	Princess	1171	3.85	3.01	3.82
	Cultivar Mean		3.27	2.83	3.18
Two	Sahara	146	3.05	2.92	3.04
Two	Sahara	292	3.07	3.03	3.13
Two	Sahara	585	3.67	3.16	3.55
Two	Sahara	1171	3.79	3.36	3.40
	Cultivar Mean		3.39	3.12	3.28
Two	Tifsport	146	3.09	2.87	3.19
Two	Tifsport	292	2.82	3.21	3.02
Two	Tifsport	585	3.44	3.08	3.76
Two	Tifsport	1171	3.60	3.49	3.72
	Cultivar Mean		3.24	3.16	3.42
	Height Mean		3.32	3.07	3.33

Table 14. Continued.

$MSDMR_{0.05†}$		0.25	0.62	0.87
$MSDC_{0.05†}$		0.27	0.19	0.3
$MSDN_{0.05†}$		0.14	0.12	0.19

Source of Variation	df			
Mowing Regime (MR)	1	*	*	NS
Cultivar (C)	3	NS	NS	NS
Nitrogen (N)	3	***	***	***
MR*C	3	NS	NS	NS
MR*N	3	NS	NS	NS
C*N	9	***	NS	NS
MR*C*N	9	NS	NS	NS

† $TMSD_{D0.05}$, Tukey's Minimum Significant Difference for comparison of mowing regime, grass, and nitrogen on tissue nitrogen.

NS, Not Significant at the 0.05 probability level.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 15. Percent tissue nitrogen as influenced by cultivar and nitrogen interaction effects.

Cultivar	Nitrogen kg ha^{-1} yr	Percent Tissue Nitrogen g kg^{-1}		
		6/20/03	7/25/03	8/28/03
GN-1	146	3.07	2.64	2.87
	292	3.04	2.80	2.89
	585	3.04	2.88	3.22
	1171	3.67	3.12	3.59
$TMSD_{D0.05}$†		0.46	NS	NS
Princess	146	2.64	2.37	2.43
	292	2.77	2.62	2.72
	585	3.05	2.60	3.11
	1171	3.52	2.82	3.55
$TMSD_{D0.05}$†		0.58	NS	NS
Sahara	146	2.96	2.59	2.67
	292	2.77	2.64	2.72
	585	3.36	2.78	3.13
	1171	3.64	2.97	3.27
$TMSD_{D0.05}$†		0.53	NS	NS
Tifsport	146	3.08	2.62	2.80
	292	3.00	2.80	2.84
	585	3.28	2.85	3.38
	1171	3.40	3.08	3.49
$TMSD_{D0.05}$†		NS	NS	NS

† TMSDD0.05, Tukey's Minimum Significant Difference for comparison of cultivar means within columns and by mowing regime.

NS, Not Significant at the 0.05 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 16. Main effects of mowing regime, bermudagrass cultivar and annual applied nitrogen on percent tissue nitrogen.

Treatments	Percent Tissue Nitrogen g kg^{-1}		
	6/20/03	7/25/03	8/28/03
Mowing Regime			
One‡	2.96	2.46	2.75
Two§	3.32	3.07	3.33
$TMSDMR_{0.05}$†	0.15	0.11	NS
Cultivar			
GN-1	3.21	2.86	3.14
Princess	2.99	2.60	2.95
Sahara	3.18	2.74	2.95
Tifsport	3.19	2.84	3.13
$TMSDC_{0.05}$∞	NS	NS	NS
N kg ha^{-1}			
146	2.94	2.55	2.69
292	2.89	2.72	2.79
585	3.18	2.78	3.21
1171	3.56	3.00	3.47
$TMSDN_{0.05}$∂	*	0.29	0.33

†$TMSDMR_{0.05,}$ Tukey's Minimum Significant Difference for comparison of mowing regime means within columns.
∞$TMSDC_{0.05,}$ Tukey's Minimum Significant Difference for comparison of bermudagrass cultivar means within columns.
∂$TMSDN_{0.05,}$ Tukey's Minimum Significant Difference for comparison of annual applied nitrogen means within columns.
NS, Not Significant at the 0.05 probability level.
* No Main Effect Due to Significant Interaction Effect.
‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower
§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

following day. Assuming the collection method did not influence results, increased shoot density under mowing regime two would allow for greater new shoot growth per unit area resulting in higher tissue nitrogen. Under mowing regime one, the 1171 kg ha^{-1} yr^{-1} treatment was above 3 g kg^{-1} in June and August. Under mowing regime two, only the 146 kg ha^{-1} yr treatment was below 3 g kg^{-1} in July and August. All other fertility treatments under mowing regime two were above 3 g kg^{-1} on all dates. This is important for manager attempting to increase tissue nitrogen levels to the 3 g kg^{-1} level. Under a higher and less frequent mowing regime, tissue nitrogen will be lower and no different if applied at the 146, 292, and 585 kg ha^{-1} yr^{-1} fertility level.

Tissue Dry Mass

Tissue dry mass was influenced by bermudagrass cultivar on four of the five sampling dates (Table 17). Tifsport had a higher dry mass accumulation than NuMex Sahara on all four dates. Princess was higher than Sahara on 4 June, 8 July, and 5 August (Table 18). Shoot density values for Tifsport and Princess were the highest among cultivars, contributing to the higher dry mass accumulations. GN-1 had a greater shoot density than Sahara and lower than Tifsport and Princess but equaled all cultivars in tissue dry mass.

Nitrogen fertility was significant on three of the five sampling dates (Table 18). The excessive treatment of 1171 kg ha^{-1} yr and the minimal treatment of 146 kg ha^{-1} yr were different on three dates. The 1171 kg ha^{-1} yr treatment was also different from the 292 kg ha^{-1} yr treatment on 6 June. On 28 August and 29 September, 1171, 585, and 292 kg ha^{-1} yr^{-1} were not different in the highest group. The 146, 292 and 585 kg ha^{-1} yr^{-1} treatments were not different on the same date.

The results showed a trend for slower bermudagrass growth in September and October. A measurement of growth is important for quick recovery from traffic. No variety showed a higher amount of tissue dry mass production in October. Sahara showed the smallest difference between the largest monthly dry mass and the smallest. In September, other cultivars were not different than Sahara but are greatly reduced from the highest monthly dry mass. The slower growth rate supported lower pre-traffic percent coverage values on 29 September and 13 October.

Table 17. Dry mass clipping yield as influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen kg ha^{-1} yr^{-1}	Clipping Yield in grams				
			6/20/03	7/25/03	8/28/03	9/29/03	10/28/03
One‡	GN-1	146	25.46	49.22	27.53	14.38	12.26
One	GN-1	292	25.06	45.78	41.22	16.31	7.90
One	GN-1	585	42.77	76.78	39.17	20.28	17.87
One	GN-1	1171	47.96	59.92	53.48	27.55	21.15
	Cultivar Means		35.31	57.92	40.35	19.63	14.80
One	Princess	146	21.70	40.75	29.82	16.92	14.90
One	Princess	292	13.75	48.75	33.17	31.68	17.54
One	Princess	585	35.27	58.30	44.67	28.31	16.59
One	Princess	1171	47.39	67.85	55.99	38.88	22.88
	Cultivar Means		29.53	53.91	40.91	28.95	17.98
One	Sahara	146	22.82	32.01	22.86	11.45	17.69
One	Sahara	292	22.37	24.93	23.09	13.76	12.52
One	Sahara	585	25.75	26.71	22.93	18.48	19.13
One	Sahara	1171	32.50	31.35	28.02	16.78	20.60
	Cultivar Means		25.86	28.75	24.23	15.12	17.49
One	Tifsport	146	34.17	38.93	23.27	12.64	15.70
One	Tifsport	292	25.22	58.65	38.59	23.20	13.98
One	Tifsport	585	28.04	79.38	47.18	25.28	24.28
One	Tifsport	1171	47.94	70.74	51.59	40.45	16.94
	Cultivar Means		33.84	61.93	40.16	25.39	17.73
	Height Mean		31.14	50.63	36.41	22.27	17.00
Two§	GN-1	146	27.61	12.13	25.31	11.71	7.00
Two	GN-1	292	22.13	12.35	26.81	15.30	7.17
Two	GN-1	585	27.35	13.03	24.02	19.17	11.02
	GN-1	1171	34.46	10.67	33.84	16.33	8.04
	Cultivar Means		27.89	12.05	27.49	15.63	8.31
Two	Princess	146	26.48	18.06	15.49	12.85	9.74
Two	Princess	292	31.22	22.72	35.04	19.81	10.56
Two	Princess	585	40.51	38.92	33.68	18.75	8.32
Two	Princess	1171	41.76	30.99	34.70	18.09	8.33
	Cultivar Means		34.99	27.67	29.73	17.38	9.24
Two	Sahara	146	25.95	11.68	17.48	8.89	6.74
Two	Sahara	292	21.86	9.44	18.14	11.26	7.61
Two	Sahara	585	26.39	13.19	20.40	12.91	9.04
Two	Sahara	1171	33.01	13.94	25.52	16.51	9.00
	Cultivar Means		26.80	12.06	20.39	12.39	8.10
Two	Tifsport	146	38.35	22.04	23.82	16.84	12.43
Two	Tifsport	292	53.73	34.44	48.90	32.37	14.76
Two	Tifsport	585	42.12	28.08	29.03	23.99	14.35
Two	Tifsport	1171	48.71	26.16	36.16	22.69	10.25
	Cultivar Means		45.73	27.68	34.48	23.97	12.95
	Height Mean		33.85	19.87	28.02	17.34	9.65

Table 17. Continued.

$MSDMR_{0.05†}$		9.05	41.10	31.86	9.82	21.06
$MSDC_{0.05†}$		10.32	17.49	16.48	9.38	3.49
$MSDN_{0.05†}$		8.88	14.21	10.63	6.73	5.12

Source of Variation	df				p>f	
Mowing Regime (MR)	1	NS	NS	NS	NS	NS
Cultivar (C)	3	*	**	*	*	NS
Nitrogen (N)	3	***	NS	***	***	NS
MR*C	3	NS	NS	NS	NS	NS
MR*N	3	NS	NS	NS	NS	NS
C*N	9	NS	NS	NS	NS	NS
MR*C*N	9	NS	NS	NS	NS	NS

†$TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison of mowing regime, cultivar, and nitrogen fertility.

NS, Not Significant at the 0.05 probability level.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 18. Main effects of mowing regime, bermudagrass cultivar and annual applied nitrogen on clipping dry mass.

Treatments	Clipping Dry Mass in Grams				
	5/5/03	6/4/03	7/8/03	8/5/03	9/5/03
Cultivar					
GN-1	31.60	34.98	33.92	17.63	11.55
Princess	32.26	40.79	35.32	23.16	13.61
Sahara	26.33	20.41	22.31	13.75	12.79
Tifsport	39.79	44.80	37.32	24.68	15.34
$TMSDC_{0.05}$∞	9.89	19.21	12.39	7.68	NS
N kg ha^{-1}					
146	27.82	28.10	23.20	13.21	12.06
292	26.92	32.13	33.12	20.46	11.51
585	33.53	41.80	32.64	20.90	15.08
1171	41.72	38.95	39.91	24.66	14.65
$TMSDN_{0.05}$∂	9.52	NS	12.36	7.75	NS

∞$TMSDC_{0.05,}$ Tukey's Minimum Significant Difference for comparison of bermudagrass cultivar means within columns.

∂$TMSDN_{0.05,}$ Tukey's Minimum Significant Difference for comparison of annual applied nitrogen means within columns.

NS, Not Significant at the 0.05 probability level.

* No Main Effect Due to Significant Interaction Effect.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Tissue Moisture Content

The cultivar by nitrogen interaction effect on tissue moisture content was significant on one of the five sampling dates (Table 19). Nitrogen influenced tissue moisture content on four of the five sampling dates (Table 19 and 20). Treatments with 1171 and 146 kg ha yr^{-1} were different from each other on 20 June, 25 July, and 29 September (Table 20). While the two remaining dates were numerically similar to the other dates, these two dates were not statistically different for 1171 and 146 kg ha^{-1} yr^{-1}. Increasing nitrogen fertility did increase bermudagrass tissue succulence. Traffic injury indicated that increasing tissue succulence was not detrimental to traffic tolerance of bermudagrass. The bermudagrass in this experiment did not perform as the cool season grasses discussed by Shearman (1989) and Beard (1973) where excessive nitrogen fertilization decreased the traffic tolerance by increasing tissue succulence.

Table 19. Tissue moisture content as influenced by mowing regime, bermudagrass cultivar, and annual applied nitrogen.

Mowing Regime	Cultivar	Nitrogen kg ha^{-1} yr	Water (grams)				
			6/20/03	7/25/03	8/28/03	9/29/03	10/28/03
One‡	GN-1	3	9.54	21.07	5.30	2.39	2.85
One	GN-1	6	6.73	17.94	13.17	4.19	1.52
One	GN-1	12	39.40	50.80	14.74	5.72	9.49
One	GN-1	24	29.01	32.47	11.31	10.04	11.09
	Cultivar Means		21.17	30.57	11.13	5.59	6.24
One	Princess	3	4.85	17.47	13.16	5.78	5.39
One	Princess	6	16.80	30.62	8.45	16.69	7.85
One	Princess	12	18.62	30.24	23.36	9.46	9.71
One	Princess	24	44.61	110.07	15.53	18.03	13.32
	Cultivar Means		21.22	47.10	15.13	12.49	9.07
One	Sahara	3	6.24	6.15	2.69	2.67	2.38
One	Sahara	6	4.64	6.00	3.92	2.96	2.76
One	Sahara	12	11.60	9.52	4.52	4.57	3.49
One	Sahara	24	18.50	15.46	11.29	5.74	8.95
	Cultivar Means		10.25	9.28	5.60	3.99	4.40
One	Tifsport	3	21.42	14.70	4.97	2.95	6.63
One	Tifsport	6	9.51	28.44	9.35	7.97	5.05
One	Tifsport	12	13.18	53.34	11.00	6.76	12.95
One	Tifsport	24	54.81	42.16	23.48	21.74	6.91
	Cultivar Means		24.73	34.66	12.20	9.86	7.89
	Height Mean		19.34	30.40	11.01	7.98	6.90
Two§	GN-1	3	23.69	10.86	14.81	11.74	6.14
Two	GN-1	6	23.52	9.81	10.73	13.74	5.82
Two	GN-1	12	21.20	12.40	7.54	20.04	9.89
Two	GN-1	24	39.96	16.75	18.72	11.25	6.56
	Cultivar Means		27.09	12.46	12.95	14.19	7.10
Two	Princess	3	17.62	12.15	1.05	14.83	9.02
Two	Princess	6	24.44	20.70	8.55	24.23	7.83
Two	Princess	12	43.48	35.77	9.92	21.79	5.35
Two	Princess	24	51.85	31.04	10.96	23.01	6.76
	Cultivar Means		34.34	24.91	7.62	20.97	7.24
Two	Sahara	3	18.98	12.28	2.99	4.16	4.77
Two	Sahara	6	12.70	9.59	4.39	8.67	7.44
Two	Sahara	12	29.21	14.17	4.14	6.81	7.21
Two	Sahara	24	40.80	17.26	9.87	11.92	6.54
	Cultivar Means		25.42	13.32	5.35	7.89	6.49
Two	Tifsport	3	35.82	13.53	3.81	11.44	8.24
Two	Tifsport	6	53.31	30.97	12.15	28.80	13.85
Two	Tifsport	12	42.49	22.25	10.63	22.97	13.25
Two	Tifsport	24	50.93	25.29	18.72	23.08	6.34
	Cultivar Means		45.64	23.01	11.33	21.57	10.42
	Height Mean		33.12	18.43	9.31	16.16	7.81

Table 19. Continued.

$MSDMR_{0.05†}$		39.64	52.54	10.23	1.09	14.20
$MSDC_{0.05†}$		15.72	26.05	11.85	12.42	4.34
$MSDN_{0.05†}$		13.07	14.33	9.53	6.13	4.25

Source of Variation	df				p<f	
Mowing Regime (MR)	1	NS	NS	NS	***	NS
Cultivar (C)	3	*	NS	NS	NS	NS
Nitrogen (N)	3	***	***	*	**	NS
MR*C	3	NS	NS	NS	NS	NS
MR*N	3	NS	NS	NS	NS	NS
C*N	9	NS	*	NS	NS	NS
MR*C*N	9	NS	NS	NS	NS	NS

†$TMSD_{D0.05,}$ Tukey's Minimum Significant Difference for comparison of mowing regime, cultivar, and nitrogen fertility.

NS, Not Significant at the 0.05 probability level.

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

‡ Mowing regime one is weekly mowing at 3.8 cm a with rotary mower

§ Mowing regime two is 3 times weekly mowing at 1.9 cm with a reel mower

Table 20. Main effect of nitrogen on tissue moisture content.

Nitrogen kg ha-1 yr	Grams of Water Lost After Drying				
	6/20/03	7/25/03	8/28/03	9/29/03	10/28/03
146	17.27	13.53	6.10	7.00	5.68
292	18.96	19.26	5.80	13.41	6.51
585	27.40	28.56	7.86	12.27	8.92
1171	41.31	36.31	14.98	15.60	8.31
$TMSD_{D0.05}$†	15.15	20.16	9.09	8.04	NS

†$TMSD_{0.05,}$ Tukey's Minimum Significant Difference for comparison of nitrogen means within columns.

NS, Not Significant at the 0.05 probability level.

Soil Penetrometer Measurements

Penetrometer measurements revealed a mean depth of resistance in the trafficked soil of 11.05 cm while the non-trafficked soil was 14.17 cm. This yields a 3.12 cm difference in soil compaction depth where root penetration may be impeded. When analyzed, these results were not significant at the 95% confidence interval level. This study was done on a modified sand root zone with moisture controlled at the time of traffic. It is possible to have a higher level of compaction if traffic occurred on a wet soil. Soil structure is easily destroyed in wet soil conditions. An assumption from this experiment is that traffic on a finer textured soil would produce a higher level of compaction. The analysis revealed that no treatments influenced the level of compaction.

SUMMARY

This study evaluated the wear tolerance of four bermudagrass cultivars under two different mowing regimes and four nitrogen fertility levels. The focus of this research was to provide a realistic traffic simulation to provide data for best management practices for bermudagrass athletic fields to maintain turfgrass coverage. The interaction effects of this research make it difficult to provide a best management strategy for all bermudagrass athletic fields. Instead, managers should use this research to make informed decisions on management techniques.

This research utilized digital image analysis to determine turfgrass coverage values. Digital image analysis provided an objective method of measuring percent coverage and comparing turfgrass injury and recovery. The goal of digital image analysis was to remove human subjectivity with injury ratings or traffic turfgrass to a predetermined end point. Although the process was labor intensive, digital image analysis served as a valuable tool in quantifying turfgrass coverage in this experiment.

When considering traffic injury by cultivar, Sahara had the greatest injury on four dates. The improved performance of the seeded variety, Princess, allows athletic field mangers the option of a seeded cultivar that is comparable to the vegetative hybrids Tifsport and GN-1 tested here. The advantage of a seeded cultivar is the ability to re-seed worn areas each year with the same variety given the grass has adequate time to establish. This experiment subjected established cultivars to traffic and the effects of traffic on newly planted, sprigged, or sodded bermudagrass is uncertain. NuMex Sahara has been used as a standard bermudagrass for re-seeding worn areas for many years.

This study showed that NuMex Sahara did not perform to the level of the other cultivars tested but may produce an adequate surface under the proper management practices. Lower and more frequent mowing decreased the injury to Sahara most dramatically. Tifsport coverage values dropped in the September and October ratings. It is also significant to consider that removing extra leaf tissue by mowing combined with intense fall traffic may stress the recuperative potential of Tifsport by depleting carbohydrate reserves. Further research on vertical mowing or raising the mowing height of Tifsport to increase leaf tissue deeper into the canopy should be done to help maximize management programs.

All cultivars showed higher shoot density, turf quality, and pre-traffic tissue coverage when mowed shorter and more frequently. Princess and NuMex Sahara clearly had a higher level of coverage throughout the year under lower and more frequent mowing. NuMex Sahara did not maintain adequate coverage under a higher and less frequent mowing regime when subjected to this level of traffic. GN-1 and Tifsport, both supported the level of traffic in this experiment under either mowing regime tested. Post-traffic coverage revealed that GN-1, Princess, and Tifsport performed similarly under each mowing regime. NuMex Sahara had less post-traffic coverage than the other cultivars. Under the taller, less frequent mowing regime, NuMex Sahara would not tolerate another immediate simulated traffic event and maintain adequate coverage. NuMex Sahara had greater coverage values after traffic under the more frequent and shorter mowing regime. GN-1 and Tifsport both had dates in the fall where the higher, less frequent mowing regime showed less injury than the shorter and more frequent regime.

Clipping dry weight measurements revealed that growth rate slowed for all cultivars in the months of September and October. As growth rate slowed, smaller amounts of tissue removed from infrequent mowing which allowed this treatment to reduce the tissue loss stress that would be experienced in higher growth rate periods. Leaves will grow more upright in the fall of the year as day length shortens and light levels decrease (Turgeon, 1999). From the experiment, with the stress from infrequent mowing reduced because of slower growth rates, GN-1 and Tifsport still maintained adequate shoot densities to tolerate traffic.

Pre-traffic coverage values may be used to represent a level of recovery from the last traffic event. Pre-traffic coverage returned to the 90% level for most varieties throughout the study until the final two traffic simulations. Those dates showed levels in the 70 and low 80% range. These dates of 29 September and 13 October were at a time when night temperatures fell to levels below 15.5°C that decreased the recovery potential of bermudagrass. Mowing lower and more frequently produced the highest pre-traffic coverage values in the early months when tissue growth rates were the highest. Mowing more frequently removes less tissue with each mowing thereby reducing plant stress during periods of more rapid growth. Nitrogen influenced pre-traffic tissue coverage in the late summer and fall. This supported the use of fall fertilization to promote traffic recovery and maintain quality. Further research is needed to determine the influences of fall fertilization for recovery and quality on winter injury potential, carbohydrate storage, spring transition from overseeding, and leaching losses from fall applied nitrogen not utilized by the grass.

This study did not find evidence that increasing nitrogen fertilization increased traffic damage to turfgrass. It has been suggested that increased nitrogen fertility beyond a certain level will produce greater tissue succulence that will result in a lower traffic tolerance. Traffic injury did not support the hypothesis that the higher water levels increased plant susceptibility to traffic damage. Increasing nitrogen fertility levels did increase clipping yields when sampled each month. The clipping yields of plots fertilized with 1171 kg ha^{-1} yr^{-1} were greater than the 146 kg ha^{-1} yr^{-1} treatments on three dates. On other dates, treatments were not different. Increasing nitrogen fertilization above 292 kg ha^{-1} yr^{-1} level did not prove to be either beneficial or detrimental to turfgrass traffic tolerance in this experiment. For the traffic simulated in this experiment, 292 kg ha^{-1} yr^{-1} would be a minimal level of fertilization to maintain an acceptable surface coverage while 585 kg ha^{-1} yr^{-1} would be necessary to maintain an acceptable visual quality. While increased nitrogen fertilization levels, did not lower traffic tolerance, the difference in tissue nitrogen concentration between 1171 kg ha^{-1} yr^{-1} and 292 kg ha^{-1} yr^{-1} treatments averaged about 0.50 g kg^{-1}, with a possible loss of significant nitrogen thorough leaching. Managers applying nitrogen to reach tissue nitrogen levels of 3.0 g kg^{-1}, on a well drained soil, need to apply significant amounts of nitrogen. Further research is needed with controlled release nitrogen sources to determine the interaction of turfgrass recovery from traffic injury, tissue nitrogen levels, and nitrogen lost through leaching.

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VITA

William Dustan Robinson
509 W. Tom Green
Brenham, TX 77833
wrobinson@ag.tamu.edu

Education	Texas A&M University, College Station, TX Master of Science, Agronomy. May, 2005
	Texas A&M University, College Station, TX Bachelor of Science, Agronomy. Turf Management Option. Minor, Horticulture May, 2001
Experience	Urban Agronomist/Manager Glasco and Co. Landscaping, Brenham, TX Jan 2003 – Present
	Turfgrass Research Technician. Texas A&M Experiment Station, College Station, TX June 2001 – Jan 2003
	Student Worker Texas A&M University Athletic Field Staff, College Station, TX January 1998– May 2001
	Greenhouse Student Worker South Plains College, Levelland, TX January 1997 – Aug 1997
	Owner Lawn Care Business, Levelland, TX March 1994 – August 1997